Global disdrometer observations and modes of rain drop-size distributions

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Motivation

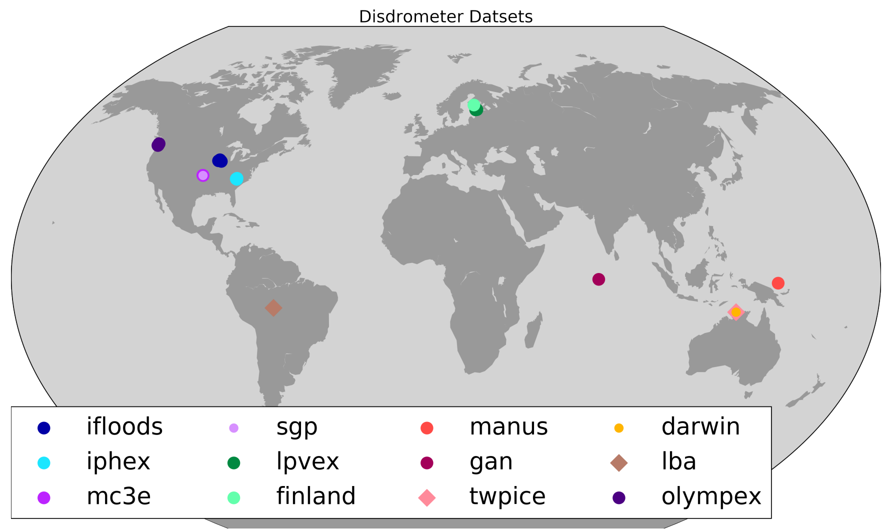
- Knowledge of drop size distributions (DSD's) underpins radar-based rainfall estimation and attenuation correction. DSD's also needed for cloud models where size distributions are assumed (so-called bulk models).
- Retrieval of rain rates from GPM DPR
  - Inherent dependence of Z-R relationships on DSD's
- DSD's are shaped by microphysical processes
  - Coalescence, accretion (riming), aggregation, break-up, etc.
  - Characteristics of convective and stratiform precipitation
- Goals:
  - Investigate DSD variability regionally and globally
  - Relate observed variability of DSD's to precipitation physics, including convective and stratiform precipitation, and contributions from ice-based and warm rain precipitation

$$Z = \int N(D) D^6 dD$$

$$R \propto \int N(D) D^{3.67} dD$$

Methods

- Employ 12 disdrometer datasets from around the world
  - Low to high latitude, continental to oceanic
  - 6 NASA field campaigns (TRMM-LBA, LPVEx, MC3E, IFloodS, IPHEx, OLYMPEx)
  - 6 DOE installations/campaigns [Gan, Manus, TWP-ICE, Darwin, Southern Great Plains (SGP), Finland]
  - Gamma DSD parameters computed including N_w, D_0, μ
  - Nearly 250,000 raining minutes included in dataset (~ 6 months of continuous rain)

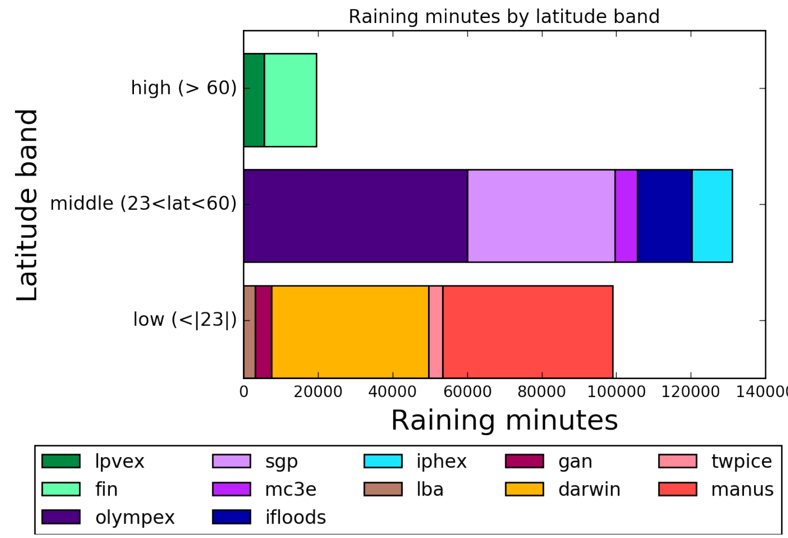


$$N_w = \frac{3.67^4 10^3 \mathrm{LWC}}{\pi \rho_w D_0^4}$$

N_w, normalized intercept parameter

Datasets

Name	Location	Time Frame	# raining points	# disdrometers / type
iFloods	Eastern Iowa	6 Apr –16 Jun 2013	14608	6 2DVDs
MC3E	Central Oklahoma	23 Apr – 1 Jun 2011	6043	5 2DVDs
SGP	Central Oklahoma	28 Feb 2011 – 5 May 2016	39592	1 2DVD
IPHEx	Western North Carolina	25 Apr – 16 Jun 2014	10718	5 2DVD
LPVEx	Helsinki, Finland	9 Sept – 20 Oct 2010	5574	3 2DVD
Finland	Hyytiala, Finland	15 Feb – 11 Sept 2014	13945	1 2DVD
Manus	Manus Island	01 Dec 2011 – 04 Jul 2014	45664	1 2DVD
Gan	Gan Island, Maldives	05 Oct 2011 – 06 Feb 2012	4348	1 2DVD
TWPICE	Darwin, Australia	3 Nov 2005 – 10 Feb 2006	3669	1 JWD
Darwin	Darwin, Australia	1 Mar 2011 – 04 Jan 2015	42248	1 2DVD
LBA	Rodonia, Brazil	17 Jan 1999 – 3 Mar 1999	3100	1 JWD
OLYMPEX	Olympic Peninsula	31 Oct 2015 – 16 Jan 2016	60091	3 DVDs*
Global			249600	

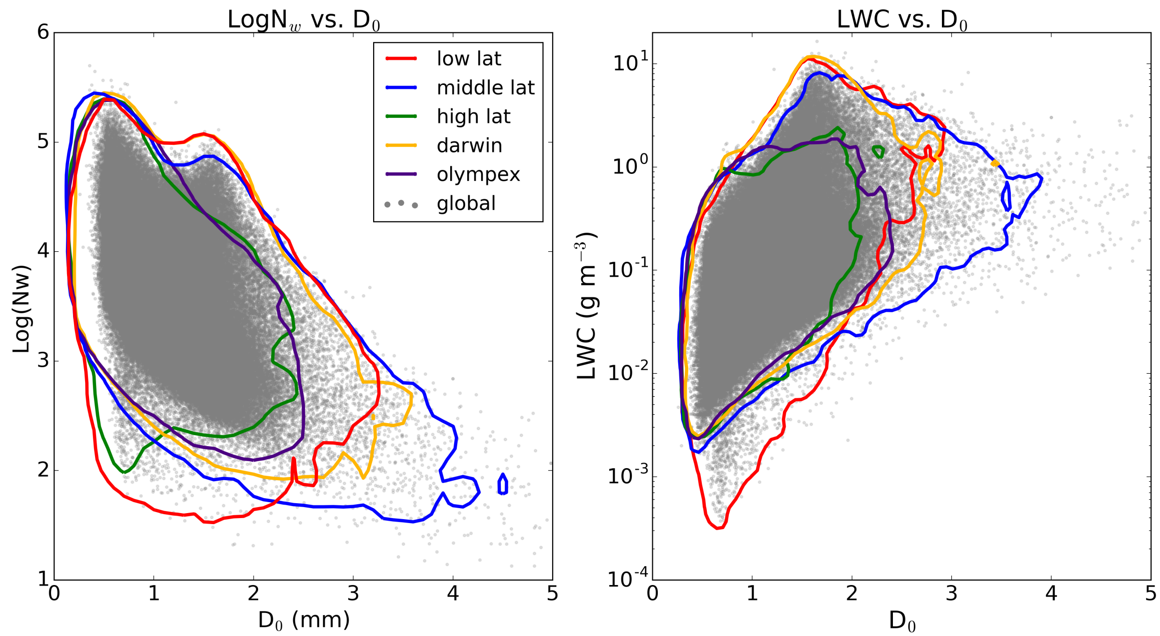


Valid "raining minute":

- Contains >100 drops
- Rain rate > 0.05 mm hr^{-1}
- $-4 \leq \mu \leq 15$
- Snow samples not considered

DSD parameters by latitude band

- N_w-D_0:
  - Low N_w, large D_0 in mid-latitudes, plus Darwin "break" convection
  - Tropics show a double peak in D_0 at high N_w (return to this later). Also evident in mid-latitudes, contributed by the long SGP dataset.
- D_0-LWC (g m^{-3}):
  - Peak LWC increases from high to low latitude
  - Large LWC-D_0 space extends to the far right in middle latitudes



But the important questions are:
- **How do these DSD parameters and their moments (LWC, RR) vary together?**
- **Accordingly, what can be said about the precipitation characteristics (convective vs. stratiform; ice based vs. warm rain)?**

EOF-Principal Component Analysis-used for detailed analysis

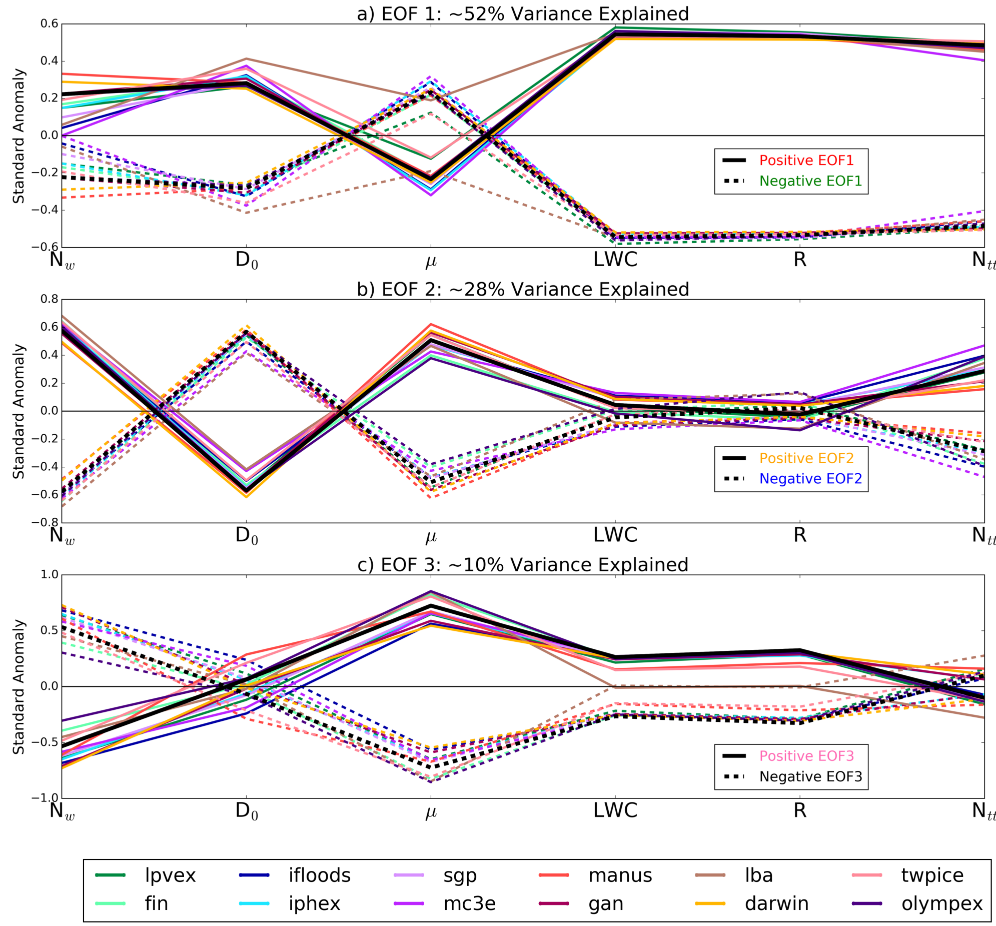
- Technique to simplify the analysis of large, complex datasets
- Type of cluster or pattern analysis using linear regression to explain main modes of variability
  - Linear regression of multiple variables simultaneously
- Project data onto set of basis vectors
  - Resulting vectors are EOFs (empirical orthogonal functions)
  - EOF's are sorted by the the amount of variability they explain in the DSD behavior
    - Collectively the EOFs explain the interrelationships between variables
  - **Each EOF has a positive and negative mode (principal components)**
  - Each raining minute data point can be described by linear combination of EOF vectors
    - Coefficients (principal components, PCs) are a measure of resemblance between a data point and an EOF vector
- **Here we examine six characteristic quantities: N_w, D_0, μ, LWC, RR, N_{tt}**
- **The covariance of these six parameters is revealed**

Results

- ***There is systematic behavior of the six DSD parameters across all latitude zones***

- ***80% of the variability (or co-variance of the six parameters) explained by first two EOF's***

Experiment	EOF1	EOF2	EOF3	Total
LPVEx	46	25	14	86
Finland	50	28	13	92
IFloodS	51	32	11	94
IPHEx	57	27	11	94
SGP	51	28	11	90
MC3E	51	32	10	93
Manus	56	26	7	89
Gan	56	26	10	92
Darwin	58	26	9	93
TWPICE	56	26	12	95
LBA	53	28	12	93
OLYMPEX	49	32	13	94
Global	**52**	**28**	**10**	**91**



Thick black line is the entire (global) dataset

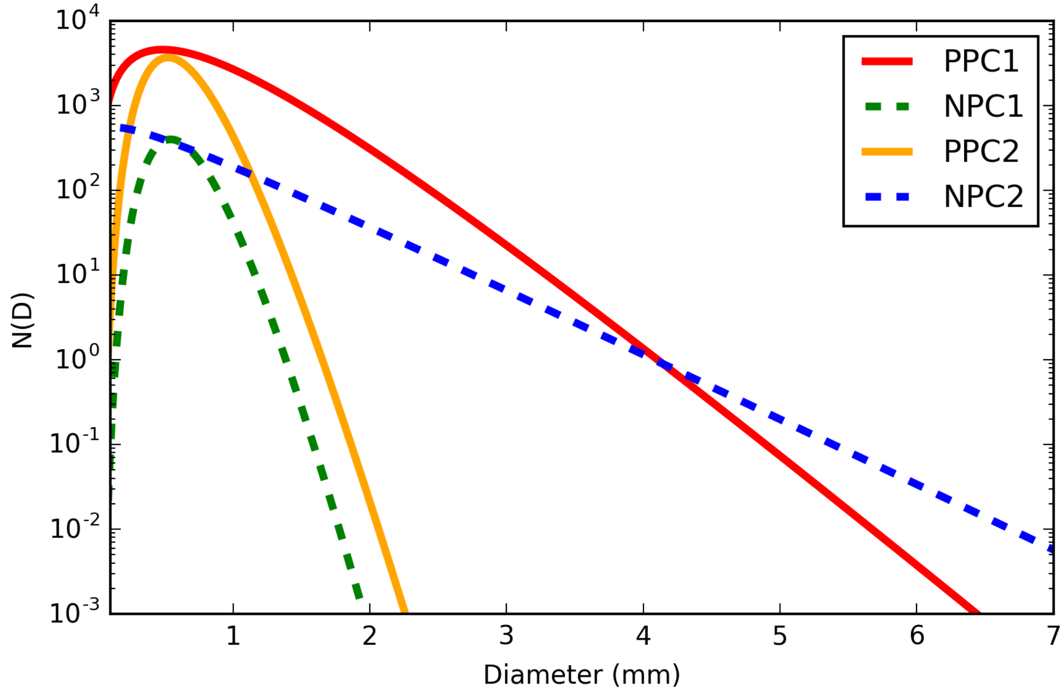
Results—mean DSDs for PC1, PC2

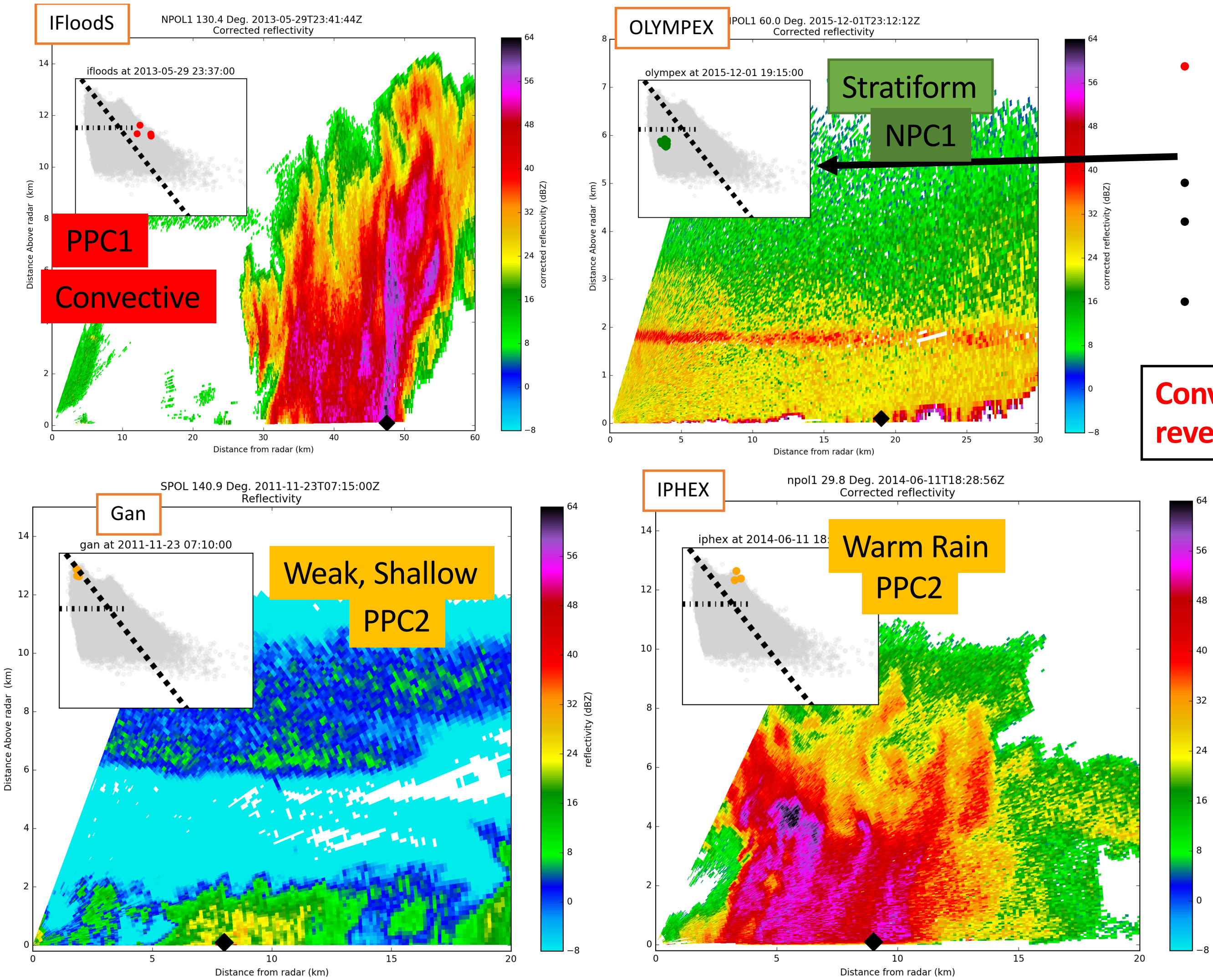
- Gather all DSDs that follow the co-variance represented by the individual PC modes and average the data to get mean DSDs. Regional PC's are normalized by the global dataset to afford an apples to apples comparison.

- These are the mean DSDs that fall out of the first 2 EOF's.

- Are these DSD's associated with specific microphysical processes like convective vs. stratiform rain, ice-based vs. warm rain?

- Examine snapshots of radar data along with N_w, D_0 pairs.





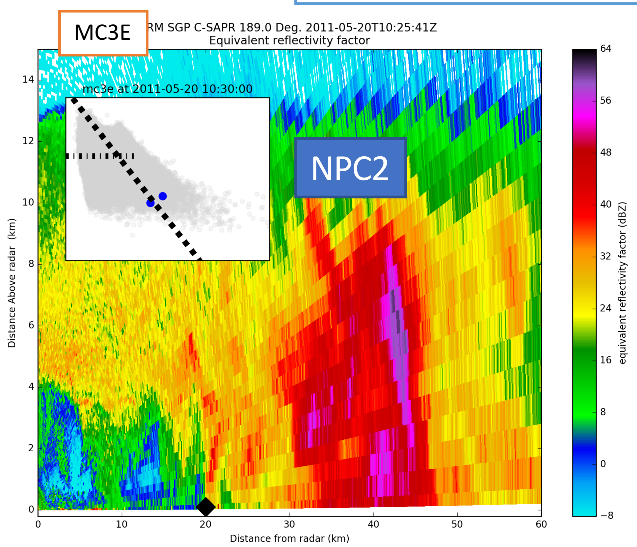
- **Inset illustrates corresponding disdrometer data in $\log N_w$-D_0 space**
- Points color-coded by PCs
- Dashed line is Bringi et al. 2009 C-S line
- Dash-dot line is Thompson et al. 2015 C-S line

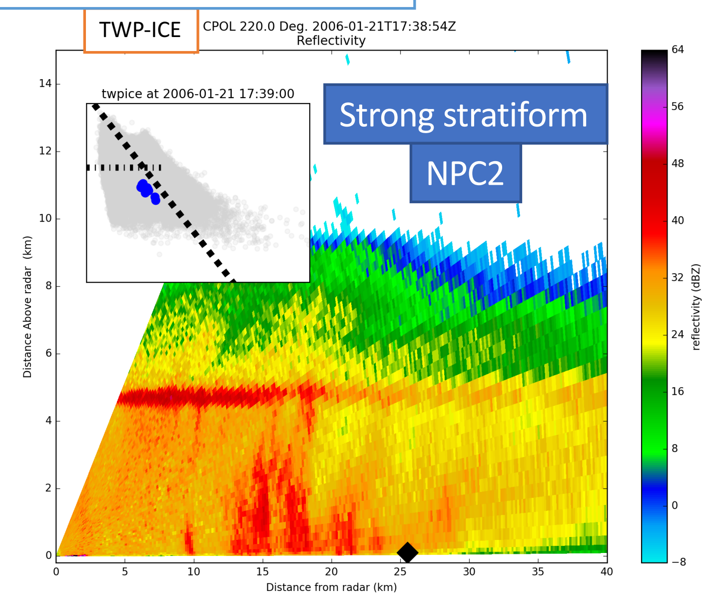
Convective and stratiform modes are revealed by PPC1, NPC1

PPC2 reveals two 'types' of warm rain, separated by D_0:

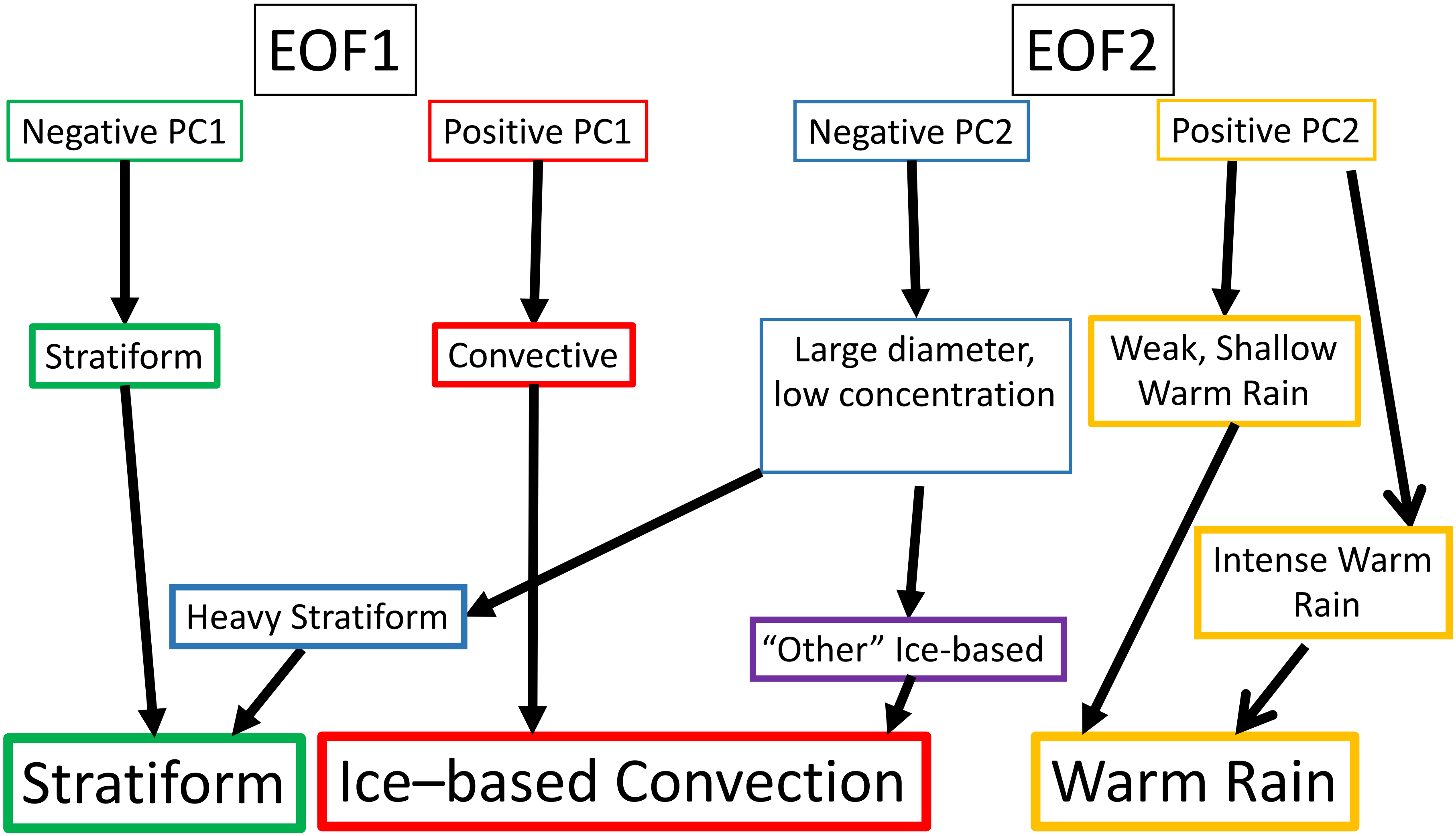
- Weak, shallow convection
  - High concentrations, small drops
- Deep warm cloud
  - Efficient coalescence process
  - Possibly equilibrium distribution (balance between collision/coalescence and breakup)

Large drop, low concentration modes indicated by NPC2





- Some cases are strong convection
- Large drops falling adjacent to strong updrafts in other cases
- Still seeking full explanation
- Strong stratiform (aggregation, coalescence)

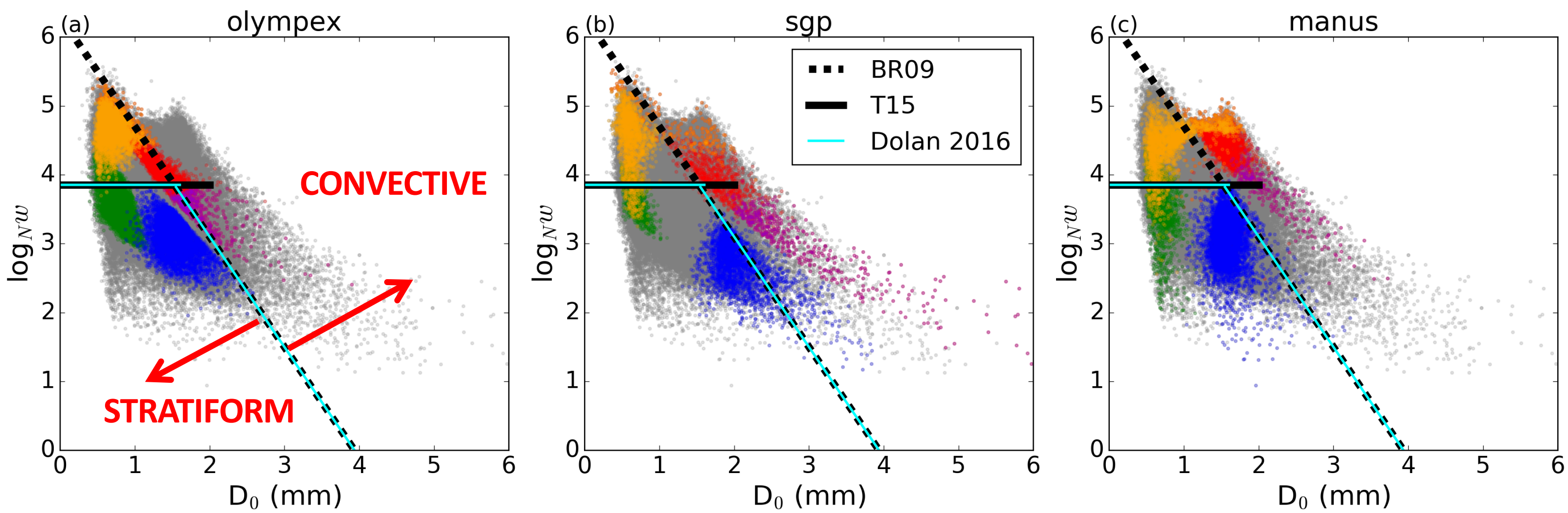

EOF1
EOF2
Negative PC1
Positive PC1
Negative PC2
Positive PC2
Stratiform
Convective
Large diameter, low concentration
Weak, Shallow Warm Rain
Intense Warm Rain
Heavy Stratiform
"Other" Ice-based
Stratiform
Ice–based Convection
Warm Rain

Rain type "Separation"

(Normalized) Negative and positive principal components PC1 and PC2 lie in different quadrants of the N_w-D_o spectrum

- Convection in OLYMPEX clearly distinguished from SGP and tropical convection in N_w-D_0 space; warm rain with larger D_0 values emerges at Manus (and other deep tropical locations)
- Some overlap (e.g. stratiform, warm rain), hence some ambiguity in rain type

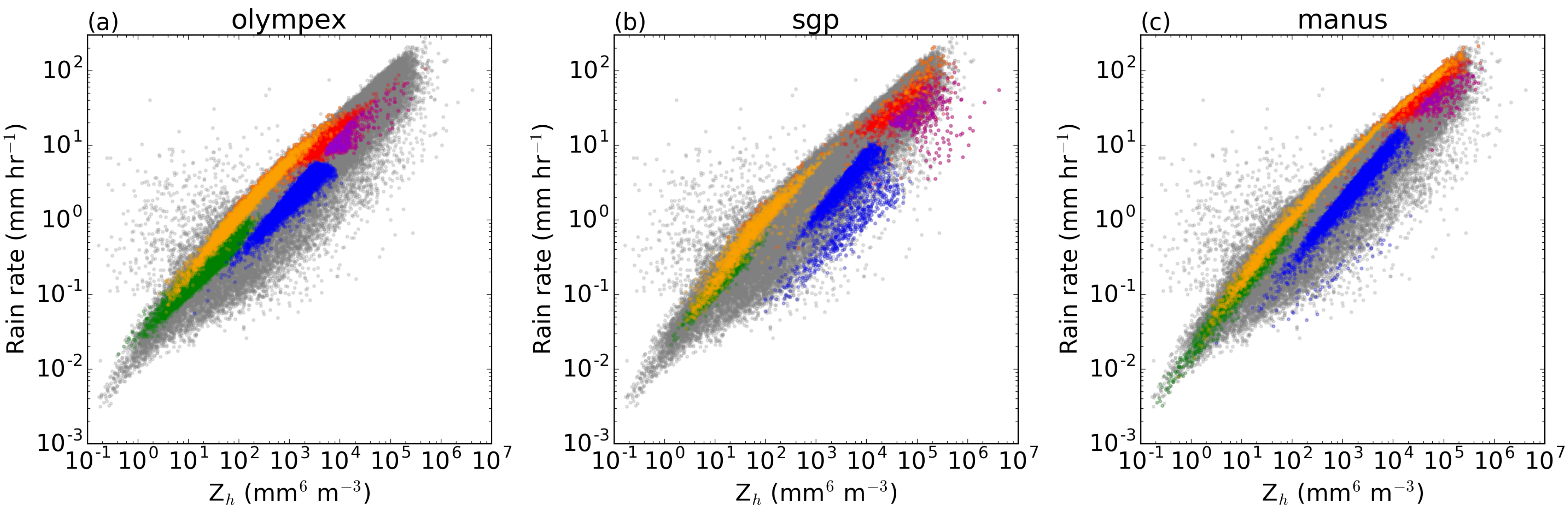
- It appears that merging Thompson et al. (2015) and Bringi et al. (2009) boundaries for global convective-stratiform rain separation is a good approach
    - Better captures weak, shallow convection (tropical maritime) and intense convection (mid-latitudes)



Convective Stratiform Warm rain Strong stratiform "Other" ice-based

Reflectivity – Rain rate

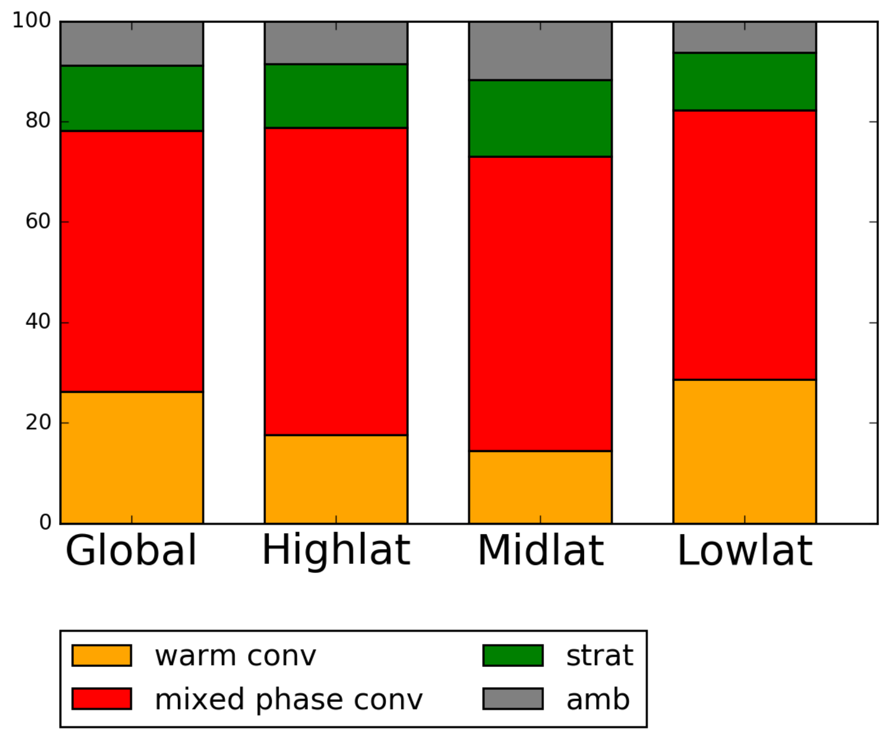
- Precipitation processes identified by EOF's are clearly separated in Z-R space
    - Stratiform-convective rain rate transition appears to increase from high to low latitudes
    - Overlap between stratiform and warm rain DSD's again seen in Z-R



Convective Stratiform Warm rain Strong stratiform "Other" ice-based

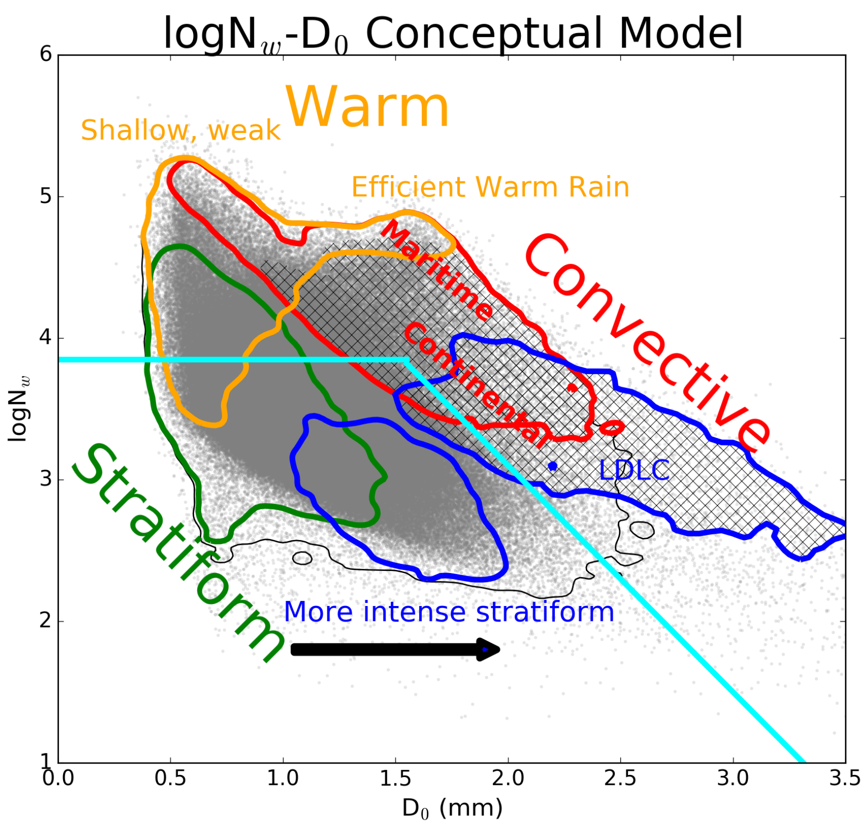
Rain Volume

- Globally:
  - 13% stratiform
  - 52% ice based convection
  - 26% warm rain (shallow and intense)
  - 9% ambiguous
- Largest warm rain component in the tropics; expected but this is a good physical check on results
- Rain volumes by precipitation type are not widely different across regions



Conclusions

- No a priori assumptions made about the DSD for convective and stratiform precipitation
- We related D_0-N_w pairs to microphysical processes and precipitation type
- This information can be used to refine Z-R relationships and improve reflectivity-based rainfall from satellites
- Results suggest DSD variables can be constrained within different rain types
- *Overlap between warm rain and stratiform DSDs is something we have been struggling with for year in terms of convective-stratiform partitioning*



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